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Synthesis of Studies on Speed and Safety

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Studies on the relationship between speed and safety are compiled, and an overview of research interests in the United States and elsewhere is presented. Aspects that affect speed and safety are considered. Techniques for speed management are summarized. The studies are summarized, and conclusions are drawn.

According to NHTSA crash data, in 1999 there were 6,279,000 police-reported crashes, 3,236,000 people were injured, and 41,611 people were killed. These occurrences account for economic costs of $150 billion a year. Studies indicate that the most prevalent source of human error contributing to collisions may be speed. Therefore, the study of the relationship between vehicle speed and collisions is fundamental for developing countermeasures to achieve compliance with speed regulations and to reduce the number of collisions. The relationship between travel speed and collision severity is clear: increase in travel speed leads to a dramatic increase in collision severity. However, the relationship between speed and collision involvement is more complex. Some people think that higher speeds lead to more crashes. Careful examination of the role of speed in crashes reveals another picture. Studies find that higher speeds do not lead to more numerous or more serious accidents. Moreover, compliance with speed limits is not necessarily a good measure of safety. On the other hand, motorists are self-policing to a certain degree in that they drive at reasonable speeds given the design of the different types of freeway. This paper tries to present a whole picture of studies on the relationship between speed and safety so that further exploration of the relationship can be based on a solid ground.

FACTORS AFFECTING SAFETY

Many factors can affect traffic safety, including alcohol, road characteristics, environmental factors, distraction, headway, speed limit, and speed. Because the effects of alcohol and road characteristics have been well documented, the following sections focus on the influence of the other factors.

Environment

Environmental factors affect safety by impairing visibility, decreasing stability, and reducing controllability. Precipitation, fog, sunshine, and dust storms are possible causes of impaired visibility. Rain, snow, and ice can make road surfaces slippery and thus decrease vehicle stability. These conditions also lead to reduced controllability.

de Vos considered the effect of visibility on safety (*1*). Simulation of a sudden visibility reduction showed that traffic safety is decreased. However, drivers may compensate for higher crash risk by reducing speeds, maintaining safe spacing, and driving more carefully. Council et al. analyzed the impact of adverse weather and its interactions with driver and roadway characteristics on the occurrence and injury severity of selected crash types (*2*). The results indicated that for the selected crash types, drivers appear to compensate for increased injury risks; in adverse weather, crashes are more frequent but injuries are less severe.

Slippery pavement is a factor in causing accidents. Antle et al. developed a probabilistic model of traffic safety under wet conditions (*3*). The model of the wet pavement index incorporated many variables, other than skid resistance, that affect safety, such as average daily traffic, driving difficulty, and wet weather exposure for a particular section of roads. The population of roads was divided into groups of roads having similar characteristics, and separate models were developed for different groups.

Distraction

Distraction is another major factor leading to accidents. Actions falling into this category are driving while talking, tuning the radio or adjusting the CD player, looking for directions, using a cell phone, drinking, eating, smoking, and exercising curiosity.

Reed and Green described the results of a study measuring driving performance in an instrumented vehicle with a low-cost, fixed-base driving simulator (*4*). Lane position, speed, steering wheel angle, and throttle position were observed. The drivers all periodically made simulated phone calls while driving. It was found that the simulator demonstrated good absolute validity for measuring speed control and good relative validity regarding the effects of the phone task and age on driving precision.

Headway

At given speed and weather conditions, how close can vehicles be spaced safely? The answer depends not only on cruise speed but also on entry to or exit from an automated cruising stream. Crassidis and Reynolds provided a framework for determining how much space is available to add more vehicles (*5*). Chan used two-dimensional simulation software to study the responses of vehicles in collisions, especially when they are closely spaced (*6*).

Speed Limit

According to AASHTO (*7*), a speed limit can be defined as the highest allowable speed on a section or type of road. In 1974, the U.S. government established a national speed limit of 88.5 km/h (55 mph). The unexpected benefit of the lower speed limit was a 16 percent drop in highway fatalities (*8*).

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In 1987, most states raised the speed limit from 88.5 km/h to 105 km/h (65 mph) on portions of their rural Interstate highways. There was intense debate about the increase, and numerous evaluations were conducted afterward. Elias and Lave argued that these evaluations shared a common problem: they measured only the local effects of the change, but the change must be judged by its systemwide effects (*9*). The authors found that the 105-km/h speed limit reduced statewide fatality rates by 3.4 percent to 5.1 percent, holding constant the effects of long-term trend, driving exposure, seat-belt laws, and economic factors. Godwin also studied the effect of increasing speed limits on rural Interstate highways to 105 km/h in 40 states since April 1987 (*10*). Both the average speed and the 85th percentile in speeds have increased on roads posted at 105 km/h. Various statistical approaches for estimating the effect of these higher speeds indicate that fatalities on highways posted at 105 km/h were 15 to 25 percent higher than expected in 1988.

On June 1, 1987, Victoria raised the speed limit on its rural and outer Melbourne freeway network to 110 km/h (68 mph) from 100 km/h (62 mph), but in late September 1989 the limit was removed and a 100-km/h limit was reintroduced. Sliogeris studied the effect of both changes (*11*). Results showed an increase in injury accident rate (including fatalities) per kilometer traveled of 24.6 percent when the speed limit was introduced in 1987 and a decrease of 19.3 percent when it was removed in 1989.

NHTSA examined the changes in fatalities that occurred on rural Interstates on which the posted speed limit was increased to 105 km/h (*12*). Of the 44,529 fatalities in 1990, slightly more than 5 percent occurred on rural Interstates with a speed limit of 105 km/h. Compared with 1989, nationwide rural Interstate fatalities in 1990 declined about 2 percent, an amount equal to the change experienced in total motor vehicle crash fatalities. This decline occurred despite increases in vehicle miles traveled estimated at 2 percent. Urban Interstate fatalities were about 2 percent higher than in 1989. TranSafety, Inc., also studied the impact of the 105-km/h speed limit on fatalities (*13*). A 3.5 percent improvement resulted from the speed limit.

In early 1996, the speed limit was raised to 113 km/h (70 mph) on Texas highways; crash frequency jumped significantly after the speed-limit change. Griffin studied crash data for the period several years before the speed-limit change and compared that history with statistical predictions for the period after the change (*14*). The study showed that crash frequency increased more than expected in 16 of those 24 scenarios, and the results illustrated a broad range of effects. For instance, the number of injury crashes on rural, multilane, undivided highways increased 9 percent, and the number of fatal and serious injury crashes on urban Interstate highways jumped 74 percent.

The National Highway System Designation Act of 1995 repealed the national maximum speed limit and returned the authority to set speed limits to the states. The Safety Management System Task Force on Speed Limits reviewed speed zoning concepts, speed statistics, and accident statistics (*15*). Whereas the speed of vehicles showed an upward trend over the last 20 years, overall accident rates showed a steady decline. However, the fatality rate on the rural Interstate system has shown a 36 percent increase since the 105-km/h speed limit went into effect in 1987.

Speed

NHTSA estimates that speed plays a role in 31 percent of all fatal crashes, which translates to 13,256 lives lost in 1995. Tens of thousands more people suffered moderate or critical injuries in speed-related crashes. The relationship between travel speed and collision severity is clear: increase in travel speed leads to a dramatic increase in collision severity. However, the relationship between speed and collision involvement is more complicated.

Liu and Popoff examined the relationship between travel speed and collision involvement on Saskatchewan provincial highways (*16*). It was found that traffic casualties and casualty rates on provincial highways were closely correlated to the surveyed average travel speed. The relationship indicates that casualties will be reduced by about 7 percent for every 1-km/h (0.62-mph) reduction in average travel speed on provincial highways. Casualty rates on provincial highways are closely correlated to speed differentials.

Aparicio et al. also studies the influence of speed on traffic safety (*17*). The relationship between the basic elements of the human-vehicle-environment system and speed and the influence of speed on the accident typology were analyzed. The selection methodology of the sites with greater accident rates was described through an analysis of accidents occurring in 1993. The instrumented vehicle CANE was used for developing the experimental study.

The U.K. Department of the Environment, Transport and the Regions funded a project to study the relationship between speed and accidents, the possible technical approaches with safety hazard analyses, public acceptance, legal implications, and implementation scenarios (*18*).

Speed is perhaps one of the most important factors affecting safety, and the relationship between speed and safety has long been a concern. However, to better understand the mechanism of how speed works, it is necessary to carefully examine what stands behind speed.

FACTORS AFFECTING SPEED

Speed Limit

Rahman and Upchurch studied Arizona's experience with raising the speed limit to 105 km/h on April 15, 1987 (*19*). Before-and-after data showed that vehicle speeds increased by only about 4.8 km/h (3 mph) or less during the four quarters following the speed-limit increase. Brown et al. studied the same experience in Alabama when the speed limit on rural Interstates was raised to 105 km/h in August 1987 (*20*). Although accident severity appeared to remain the same, the frequency of accidents on rural Interstates increased significantly, by 18.8 percent. However, the significant increase on the rural Interstates was accompanied by a nonsignificant decrease of 456 accidents in the entire state. This confounding result made it difficult to isolate the cause of various significant changes, but the overall evidence is not favorable to the recent increase in driving speeds.

Nilsson analyzed the effect of the reduced speed limit during summer l989 (*21*). The reduction in the 110-km/h speed limit in the summer of l989 on 5500 km (3,417 mi) of roads led to lower speeds than in l988 not only on the road sections involved but also on other main roads. The traffic safety situation on rural roads during summer 1989 improved in relation to the corresponding period in 1988. As expected, the improvement was greatest on those roads where the speed limit was reduced from 110 km/h to 90 km/h (56 mph), particularly on motorways. The reduction in speed was also greatest on motorways.

Anderson et al. estimated the likely effect of reduced travel speeds on the incidence of pedestrian fatalities in Adelaide, Australia (*22*). A reduction in the speed limit from 60 to 50 km/h (37 to 31 mph) was one of four speed-reduction scenarios considered. The smallest estimated reduction in fatal pedestrian collisions in the selection presented was 13 percent, for a scenario in which all drivers obeyed the existing speed limit. The largest estimated reduction was 48 percent, for a scenario in which all drivers traveled 10 km/h (6.2 mph) slower.

Rama investigated effects of weather-controlled variable speed limits and warning and information signs on driver behavior (*23*). The results showed that in winter, the reduction of the speed limit from 100 to 80 km/h (50 mph) decreased mean speeds of motor vehicles by 2.5 km/h (1.6 mph) in addition to the average decrease in mean speed by 6.3 km/h (3.9 mph) caused by the adverse road conditions. When the slippery road warning was displayed, the speed reduction was 1.8 km/h (1.1 mph) in addition to the effect of weather, which was 9.3 km/h (5.8 mph). In summer, the change from 120 (75 mph) to 100 km/h decreased the mean speed of motor vehicles by 5.6 km/h (3.5 mph).

In another study focused on speed change, Malenstein and van Loosbroek described a pilot for continuous applied speed enforcement (CASE 1) (*24*). The objective was to reduce speed violations to a maximum 5 percent. The research found that before this pilot, the speed limit was violated by 35 percent of motorists, increasing to almost 70 percent at night. During this pilot, the average of violators was 3 percent; realization of an objective of maximum 10 percent violation on 100-km/h segments appeared to be feasible.

Environment

Environmental factors affect not only mean speed but also speed variance, because of the difference in driver experiences and characteristics. Liang et al. found that the standard deviation of speed doubles during fog events and triples during snow (*25*). Liang et al. also found that drivers reduce their speeds an average of 1.1 km/h (0.7 mph) for every 1.6 km/h (1 mph) that the wind speed exceeds 40 km/h (25 mph).

May considered the effects of capacity reduction due to environmental factors like snow, rain, and fog. He concluded that recommended free-flow speeds for different weather conditions of clear and dry, light rain and light snow, heavy rain, and heavy snow were 120 km/h, 110 km/h, 100 km/h, and 70 km/h (43 mph), respectively (*26*). Kyte and Khatib conducted a study to identify the effects of environmental factors on free-flow speed (*26*). The environmental factors evaluated were visibility, road surface condition, precipitation intensity, and wind speed. Both aggregated and disaggregated effects were discussed, and the authors concluded that the effect of light precipitation, a reduction of 14.1 to 19.5 km/h (8.8 to 12.1 mph), was about 50 percent higher than the 10-km/h reduction recommended by May. The effect of heavy rain [31.6-km/h (19.6-mph) reduction] was also 50 percent higher than in May's study [20-km/h (12.4-mph) reduction]. High-speed wind was a new variable that can be used in estimating free-flow speed, and the estimated effect was a 9-km/h (5.6-mph) reduction in free-flow speed for wind above 48 km/h (29 mph).

Andrey and Knapper studied how various driver groups differ in their perceptions and adjustments to weather hazards through a telephone survey (*27*). Survey results suggested that most drivers recognize the seriousness of the traffic safety problem and in fact had a fairly accurate impression of the relative risk associated with various driving conditions. Despite this, the range of driver adjustments invoked during inclement weather generally did not reflect the magnitude of the weather hazard. Results suggested that countermeasure programs should focus either on improved skills training or on ways to induce greater caution during inclement conditions.

Driver Behavior

In a driver-vehicle-road system, the driver is the most flexible but unstable component. Driver behavior links directly with vehicle speed and safety. Among other things, speeding has been recognized for decades as a significant, and highly complex, safety issue. An FHA study concluded that 7 of 10 drivers exceeded the speed limit in urban areas, and compliance was worse on low-speed roads (*28*). Gabany et al. investigated the factors that predispose, enable, and reinforce driver speeding behavior (*29*). A perceptual inventory was developed and administered to a large, college-age sample. High levels of internal consistency were found. The perceptual inventory approach showed promise over behavioral and attitudinal self-reports, particularly when self-reported referent criteria are difficult to obtain.

When investigating the self-enhancement bias in driver attitudes, Bathurst and Walton found that drivers rate themselves better than the average driver on safety and skill perceptions (*30*). Between 85 percent and 90 percent of drivers claimed to drive slower than the "average driver." The results support the downward comparison theory because drivers consider other drivers negatively rather than exaggerate their self-perception.

Advisory and Regulatory Information

Srinivasan and Jovanis studied how the characteristics of route guidance systems affect the attentional demand and efficiency of the driving task (*31*). Specifically, the study was conducted to understand how drivers react to complex route guidance systems under varying task demands resulting from driving on different types of roads. The findings of this study showed that for long distances, no significant differences in speed and standard deviation of speed existed regardless of the traveler information system used. However, for shorter distances, significant changes in speeds were identified. These findings suggested that drivers compensate by driving faster after a period of slowing in response to advisory information.

On the basis of medium speed and 85 percent velocity, Blanke analyzed driving behavior (*32*). The research demonstrated that all types of speed regulation signals are efficient for a reduction of car speed. In addition, the order of effect depends on the speed limit in the preceding zone and on several border conditions, such as road type, size of city, and location. By linear regression, the effect of traffic control measures on the regional smoothing of the traffic could be quantified. The hazard statistics proved a substantial improvement of traffic security in areas with smoothed traffic.

SPEED MANAGEMENT

Because speed and its impact on highway safety is an area of concern to both FHWA and NHTSA, these agencies formed a joint speed-management team in late 1994 to look at speed-related issues of interest (*33*). NHTSA and the FHWA Office of Motor Carriers have undertaken many efforts to develop innovative and effective speed-enforcement methods, strategies, and programs that include cooperative law enforcement efforts, a model speed-enforcement program in California, and comprehensive traffic-enforcement strategies for large trucks. In addition, both agencies provide public information and education focused on the public, law enforcement agencies, engineers, and the judiciary to make these groups more aware of the dangers of speeding and the steps being taken to reduce speeding-related crashes and the resulting fatalities and injuries. Speed management can be carried out in many ways, as summarized in the following.

Variable Speed Limit

Rose conducted research in the United Kingdom and the Netherlands to examine the effectiveness of the variable speed limit (*34*). Benefits were found for increased traffic throughput and improved safety. Other studies demonstrated that compliance in Europe is as much as 98 percent. Wilkie studied the use of variable speed limit systems in the United States (*35*). Although the applications were not expected to be as successful as that in Europe, the potential benefits resulted from reduction in speed variance were evident.

Camera

Malone presented a new device to detect speeding (*36*). Based on a combination of conventional radar and a large camera with a telephoto lens, the device was mounted in the back of a small truck or station wagon parked in an area where speeding was a problem.

TranSafety, Inc., studied the effects of photo radar on highway safety (*37*). The research found that (*a*) speeding decreased at all sites, but decreases were greater at the test sites; (*b*) the greatest decreases in the proportion of speeding vehicles at all sites were for vehicles traveling at the highest rates of speed; (*c*) media coverage of the use of photo radar affected the behavior of drivers at all sites; (*d*) the greatest speed reductions occurred on the six-lane test section; (*e*) the presence of signage announcing photo radar reduced speeding; and (*f*) increased enforcement presence and fully deployed photo radar units reduced speeding on the test roadways even more. Investigators believe that the reduction in speed will ultimately lead to a reduction in fatalities.

Robertson focused on a feasibility study into a revolutionary method of speed deterrent that uses the latest techniques in machine vision to identify vehicle speed and to display violation details to the road user (*38*). Similar research was conducted by Leithead, who studied surveillance cameras and their impact on driver behavior (*39*). Speed surveillance cameras were also used in Queensland, Australia. It was called the Speed Management Strategy Project and involved image processing techniques (*40*). In Norway, Amundsen reported experiments with automatic speed control, which involved the use of more than 140 cameras in permanent positions (*41*). Evaluation of the effect of the system in 1996 showed an accident reduction of 26 percent and a cost-benefit ratio of about 10.

To lower the number of high-speed violations and thus reduce road accidents, Harbord and Jones described a pilot project on the London Orbital Motorway that involved variable speed-limit enforcement (*42*). The enforcement system automatically detected and recorded vehicles exceeding the speed limit. The General Traffic Department of Kuwait installed automatic radar cameras to monitor traffic speed at a number of strategic roadway locations (*43*). Recent traffic safety records point to an increase in both the number of violations and the occurrence of road accidents. It was found that without live enforcement support and active follow-up of camera-recorded violations, the effectiveness of these cameras in improving road safety was insignificant at best, particularly in the undisciplined driving environment of the oil-rich nations in the Middle East.

Wing examined the use of automatic cameras for traffic surveillance, including photo red light systems and photo radar, and described problems encountered in enforcing these systems, focusing on the fact that there is no state legislation specifically allowing local agencies to enforce photo radar citations (*44*). Bloch compared the effectiveness of two forms of automated motor-vehicle speed control: speed display boards and photo radar (*45*). Results showed that both devices, when deployed, significantly reduce vehicle speeds by 6.4–8 km/h (4–5 mph) and particularly reduce the number of vehicles traveling 16 km/h (10 mph) over the posted limit. Supplementing the display board with intermittent enforcement significantly increased its effectiveness.

In November 1998, Denver, Colorado, adopted a photo radar system to crack down on speeders (*46*). In the first 8 h of operation, 340 drivers were caught going 16 km/h or more above the posted speed limits. In this way, Denver hoped to reduce the number of traffic accidents, injuries, and fatalities.

Gebert described a system that features an automatic speed- and traffic-light violation recording system for portable and permanent installation in one compact unit (*47*). Piezo sensors were used for speed detection, and cameras offer front, rear, or combined photographs. Another traffic-management system, SPECS (*48*), used automatic digital cameras to monitor traffic speed. The system consisted of two cameras that digitally recorded the passage of a vehicle. The time taken by the vehicle to travel between two points is then used to calculate average vehicle speed. If speeding has occurred, the cameras record the license plate, and the information is relayed to a traffic control center. The system can also be used to identify stolen and missing vehicles.

Signage

Rogerson reported a trial proposed in 1988 by the Speed Management Strategy Implementation Committee of Victoria (*49*). Its aim was to determine the effect on vehicle speeds of two electronic signs displaying "Drivers Not Speeding Last Week __ Percent." The signs were placed facing both directions of traffic on Beach Road, Sandringham, near the junction with New Street, from March 19 to May 21, 1990. Vehicle speed was measured by using the Golden River traffic classifiers. It was found that when the sign was up, fewer vehicles exceeded the speed limit of 60 km/h. The greatest effect was the reduction in the percentage of vehicles exceeding 90 km/h (60 mph), but as in previous studies, vehicle speeds increased again after removal of the sign.

Brisbane studied the effectiveness on speeding motorists of a prototype sign showing vehicular speed (*50*). The paper deals with the technology and theory used to develop the site and the results of the excessive-speed messages on the behavior of speeding motorists.

Olsen described how speed indicator displays offer a cost-effective speed deterrent in Denmark (*51*). The system included display applications, recording speed, types of detectors and controllers, mode of operation, programming and data collection, service and maintenance, and analysis software.

Garber and Srinivasan focused on evaluating the effect of duration of exposure of changeable message signs (CMS) with radar on its effectiveness in reducing speeds and influencing speed profiles in work zones (*52*). The report also studied the impact of the length of the work zone and vehicle type on speed reductions. Results of the study indicated that the duration of exposure of the CMS does not have a significant impact on speed characteristics and driver behavior. It was concluded that the CMS continues to be effective in controlling speeds in work zones for projects of long duration.

Signaling

Alessandri described controlling freeway traffic by using speed signaling and ramp metering (*53*). Optimization procedures and Kalman filtering were also employed in the proposed methodology. In another paper (*54*), Alessandri et al. examined an optimal control problem that was stated for variable speed signaling to improve congested traffic behavior. A traffic state estimator is designed to generate real-time estimates of the traffic density and to activate variable speed signaling. Simulation results were used to demonstrate the effectiveness of the proposed approach.

Speed Adaptation System

Varhelyi studied the possibilities of dynamic speed adaptation based on advanced transport telematics technology (*55*). The research proposed a system for dynamic speed adaptation and presented its effects and implications as well as an implementation strategy. In another paper (*56*), Varhelyi stated that accident risk in adverse conditions (wet or slippery road, darkness) increased drastically, and speed adaptation in these conditions was often inappropriate. The safety potential of appropriate speeds in these situations was high. Varhelyi discussed appropriate highest speeds in different conditions, and a system that limits the maximal speed of the vehicle in the actual situation (on wet or slippery road, at sharp curves, in darkness, and in decreased visibility) via in-vehicle equipment was proposed. The estimated safety effect of the proposed system was a 20 percent to 40 percent reduction of injury accidents in Sweden.

Sundberg described equipment for dynamic speed adaptation, a so-called speed checker (*57*). The speed checker was a small electronic device, mounted on the vehicle dashboard, that signals by light and sound if the driver exceeds the prevailing speed limit. The speed checker is activated by roadside radio transmitters and is linked with the vehicle speed metering system. Extensive interviews were held with the users before and after the test period. The results were astonishing: The speed checker is by far preferred to physical means for speed reduction (road bumpers, etc.). The share of the drivers equipped with speed checker that kept to the speed limits increased from 25 percent to 80 percent during the test period. Ninety percent of the users wanted the speed checker system to be expanded, and 95 percent wanted to keep the equipment in their vehicles for a prolonged period.

Gustafsson studied the acceptance of intelligent speed adaptation (ISA) and found that respondents and test personnel generally were in favor (*58*). Some field trials and questionnaires show a very high level of acceptance for informative as well as intervening systems. The acceptance of ISA systems was high, and it was even higher after subjects drove a vehicle equipped with an ISA system. Plans for large-scale trials of the ISA plan were also found in Sweden (*59*). The program focused on employing dynamic speed adaptation technologies, which range from advisory messages to active throttle control. In the southeastern part of Sweden, the application of speed adoption was based on actual weather, road, and traffic conditions (*60*). With data from the road weather information system and the traffic monitoring system, a system was planned for dynamic speed recommendations in the long term and speed restriction presented by variable message sign. The aims were to increase traffic safety and decrease environmental pollution by achieving a better speed adoption to the current situation, achieving steadier traffic flow, reducing the average speed, and decreasing the spread around the average speed. The project is also supporting the infrastructure of intelligent transportation systems in Sweden.

Traffic-Calming Techniques

A new traffic-management method called the "environmentally adapted through road" was introduced by the Danish road directorate to deal with problems caused by through traffic (*61*). By using different kinds of speed-reducing measures, vehicle speeds were slowed. Evaluation results showed that vehicle speeds were reduced significantly. The feeling of security and traffic safety have been increased.

Taylor and Wheeler focused on the problem with main roads through villages and carried out a joint study to investigate the costs, benefits, and effectiveness of suitable speed-reducing measures (*62*). They presented the results concerning the effectiveness of some of the schemes, including the accident data, together with some results from the initial monitoring. Also, for main roads passing through town and village centers, the Danish road directorate implemented traffic-calming schemes in several Danish towns. Jorgense and Mertner reported the results of a before-and-after study of the traffic-calming schemes used and concluded that positive effects can be obtained on traffic safety, risk perception, and the environmental quality of the area (*63*).

"Calming green waves" was introduced by Ellenberg and Bedeaux (*64*); this involved adjusting signal timing to encourage drivers to adopt a slower and safer yet consistent speed. Three parameters were involved in implementing the calming green wave principle: the speed of coordination, the cycle duration, and the green wave bandwidth. The goal was to choose a cycle duration that avoids too severe a restriction of flow capacity.

The DUMAS project was jointly carried out in nine European countries to manage speed and improve safety. As a part of the project, Griebe et al. provided an overview of the work on speed management in urban areas and in particular the frameworks for design and evaluation of speed-management programs (*65*).

More techniques with which to calm traffic were reported by Coulstock (*66*) and Sundberg (*67*). Jorgensen (*68*), Stark (*69*), and Coleman (*70*) provided more information on speed-management techniques and enforcement technologies.

CONCLUSIONS

- It is true that safety is closely related to speed, and an enormous number of studies have focused on it. However, a closer look at what stands behind speed may give a better understanding of speed and, consequently, safety.
- Most studies are site and time specific, so their results may not be true when generalized. What makes sense is the relationship between speed and safety in the long run. To achieve this goal, studies need to be carried out constantly and systematically.

- Many studies favor the use of a speed limit to reduce speed variance and encourage stable flow to further improve safety. However, an inappropriate speed limit is easily violated. Therefore, the speed limit must reflect real-time road, traffic, and weather conditions. A speed-limit calculation should be based on traffic flow prediction, prevailing speed, and environmental factors, so that the limit will be accepted by most drivers. This calls for variable speed limits.
- Studies found that drivers may not always accurately rate their driving behavior. This finding reminds one not to rely too heavily on data obtained by subjective methods.
- Although acceleration is supposed to have something to do with safety and accident severity, very few reports include the relationship between acceleration and safety. This could be a direction for further study.
- Recent studies showed strong interests in weather, and weather is found to have a close relationship with speed and safety. The impact of weather may include reduced visibility, stability, and controllability. All of these may alter driver behavior and contribute to accidents. However, this point did not attract sufficient attention in other studies. It is now time to include weather in considerations.
- Speed and safety issues are so interconnected that sometimes it is difficult to distinguish whether a specific factor affects safety or speed. Most often, it influences both. These factors include environmental conditions, driver behavior, and speed limit.

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